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\- COMMUNIST CHINA -

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Editor's note: This article offers a number of opinions concerning the reduction of the dead weight of structure and it is hoped that these ideas will attract greater discussion and further research.

In construction engineering, great efforts have been put into the reduction of the dead weight of structure. This is one of the important items in the content of the present technical reform and technical revolution movement. At this year's All-China Enlarged Construction Engineering Conference, sponsored by the Construction Engineering Ministry and attended by all provincial construction engineering commissioners and municipal or hsien construction engineering bureau chiefs, Vice-Minister Yang Ch'un-mao made definite demands and gave valuable instructions concerning this problem. Accordingly, the problem of how to attain the reduction of the dead weight of structure has now become one of the most important factors that attracts the attention of all construction engineers in China and it is also the most interesting problem. This article tries to discuss the problem of reducing the dead weight of structure from the position of a designer. Owing to the limitation of his knowledge, the writer may have entertained erroneous views, for which he asks his readers' indulgence.

1. The Meaning of Reducing the Dead Weight of Structure

The reduction of dead weight of structure has a very

important meaning to the national economy. As far as construction engineering is concerned, it is a very important measure in the implementation of the Party's socialist construction and general line. The reasons why this problem has attracted so much attention are:

After the dead weight of structure has been reduced, its first effect is the economy of a great amount of construction materials. At the same time, owing to the fact that structural dead weight generally constitutes a very large proportion of the total load supported by the construction structure, after the dead weight has been reduced, the size of the cross-section of the construction structure will be correspondingly reduced, thereby the amount of materials used will be also reduced.

There are many merits in the economy of construction materials: (1) Such an economy will better resolve the contradiction between China's enormous task of capital construction and the inadequate supply of construction materials. If structural dead weight were reduced and less construction materials were used, 70-80% materials would be able to complete a 100% task.

(2) It will reduce the amount of labor and expenditure used for the production, transportation and installation of the amount of construction materials that has been economized. Especially, the amount of labor and expenditure consumed in the transportation of construction materials is very enormous. The most commonly used construction materials, such as bricks, tiles, lime, sand, stones, etc., are very heavy and bulky, thus, the amount of labor required for their transportation is very large.

For example, take the case of the Construction Ministry, if the structural dead weight of all the construction tasks undertaken by this Ministry can be reduced by 10% on an annual basis, 8-10 million tons of construction materials will be economized. This means an economy of 270,000-330,000 freight cars that would otherwise be required to transport the amount of construction materials so reduced, or the economy of 1,600,000-2,000,000 heavy 5-ton trucks. In turn this means a great relief of the present congested conditions in transportation.

(3) It will reduce the manufacturing costs of construction structures. At present, materials constitute 60-80% of the total manufacturing cost of structures. Therefore, the reduction of construction materials will be a very important factor in reducing the total cost of a building structures.

If we regard the reduction of structural dead weight

as merely a means to economize construction materials and to lower the cost of a building project, this is not enough. We must take note: the reduction of structural dead weight means the reduction of structure cross-section, which in turn means greater space for effective use afforded by the building. To use light-weight materials to reduce structural dead weight will also raise structure ability to keep heat and heighten its sound-proof effect.

In addition, in an earthquake zone, special consideration must be given to the reduction of structural dead weight because in such areas the structure must support a very large horizontal earthquake load. Owing to this very large horizontal earthquake load, not only preventive measures must be adopted but the cross-section of the load supporting structural members must also be increased. Under general conditions, the horizontal earthquake load is in direct proportion to structure load; therefore, if the structural dead weight were reduced, the horizontal earthquake load can also be reduced. If aluminum alloy thin plates and high efficiency heat-proof and sound-proof materials can be made into thin plates as roofing materials, such a roof, as compared to a reinforced concrete roof, is lighter by 90-93% and the horizontal earthquake load due to the dead weight of the roof will be lowered by 67-75%.

The reduction of structural dead weight will also hasten the speed of installation. With similar hoisting crane equipment, greater pre-fabricated structural members can be hoisted, for instance, large floor slabs that can cover the entire area of a room or the pre-fabricated structure of an entire room. Under such conditions, the speed of construction can be greatly accelerated.

Summarizing the above facts, the reduction of structural dead weight can definitely fulfill the goals of "more, faster, better and cheaper." Therefore, great efforts have been exerted to seek various means to reduce the dead weight of structure. This is the most important task that confronts our construction designers today.

2. Ways to Reduce the Dead Weight of Structure

There are many ways in which the reduction of structural dead weight can be accomplished. Foreign and Chinese designers have accumulated much experience. In China, Harbin designed and built the new technical building, using pumice stones as aggregate in silicated floor slabs and slag silicated block walls. As compared with the ordinary buildings,

the structural dead weight of this new building is reduced by more than 30%. In foreign countries, especially in the Soviet Union, great attention is given to the reduction of structural dead weight. At present, the dead weight of civil buildings has been reduced from 2.5 tons to 1.1 tons per square meter, while the lowest dead weight for residential houses is only 0.76 ton per square meter. It is planned that within seven years, the average reduction of dead weight of structure and buildings will be more than 30%. Each year, the amount of materials economized will be 100-150 million tons. Here, according to experiences that are already understood, are several important ways to reduce the dead weight of structures:

(1) Improve building load supporting structural members so as to fulfill the goal of reducing the dead weight of structures.

In the entire dead weight of the building, the dead weight of the load supporting structural members constitutes 70-80%, the rest is the weight contributed by decorations and equipment; therefore, the principal way to reduce the dead weight of structures lies in the reduction of dead weight of the load supporting structural members.

(A) Adopt a reasonable design for the structural arrangement. A reasonable design for the structural arrangement will reduce the dead weight of the structure; thus, when the design for the structural arrangement is made, a careful comparison and selection must be made.

In industrial construction, a reasonable design for structural arrangement should observe the following factors: (a) Statistical data show that the squarer the external form of the area occupied by a plant building becomes, the greater the dead weight of the structure is reduced. But under general conditions, the dimensional length of a single-story plant building's area along the distance of columns is generally greater than the span. In order to make the measurements of the area come closer to the shape of a square, the dead load of the structural members of a multiple-span plant building is usually lighter than that of the structural members of the single-span plant building. The dead weight of the structural members of a single-story two-span plant building is generally lighter than that of the structural members of the single-span plant building by about 20%, while the dead weight of the structural members of the three-span plant building is again lighter than that of the structural members of the two-span plant building by about 10-15%.

Accordingly, we must do our utmost to combine all those smaller plant buildings that house similar productive operations or closely related activities, or scattered departments, smaller spans into a larger plant building. Under such conditions, the number of walls that are built to protect the structural members can be reduced. At the same time, because the number of columns along the direction of the span is increased, it is favorable to the supporting strength of the cross-wise frameworks; thus, the cross-section of the columns can be reduced. As a result, the dead weight of the structure is also reduced. In addition, a combined plant building will raise the modulus of the building's construction area, reduce the ground space of the plant building itself, and lessen the length of the engineering pipe-lines, public utility pipe-lines and adjacent roads.

(b) The measurement for the network of columns in an industrial plant building must be appropriately enlarged. Such an arrangement will better suit the development of productive techniques and the active installation of equipment and also enable the structural dead weight to be reduced to the minimum. Economic comparison shows that in a multiple-span plant building with no bridge-type cranes, the most ideal distance between columns is 12 meters and the most ideal width for spans is 18 to 24 meters. Where there is suspended transportation equipment, the distance between columns should be 12 meters. But on the supporting structure, there should be a truss structure erected at six meter intervals. Such a design is more suitable. In a multiple-span plant building with bridge-type cranes, the distance between columns should be 6-12 meters and the width of span should be 18 meters.

(c) The space arrangement of an industrial plant building should be typical and simplified. In one plant building, the spans and height should be of uniform measurement so that there will be no varying measurements in the pre-fabricated structural members. In the past, it was usually assumed that in order to reduce the volume of a plant building, its transverse section should be constructed in such a way where there would be varying heights, formulating a so-called "effective shape". But, in reality, this is incorrect. According to analysis, such an arrangement may reduce plant building volume to a certain degree, but under most conditions, the varying heights of the transverse section render the construction of the structure more complicated and the loading distribution of the transverse direction framing becomes more serious and as a result,

production cost will be higher.

As to the problem of whether the plant building should be constructed on the basis of one story or of multiple stories, it should be decided on the basis of the actual conditions. In general, one-story plant buildings are more economical than the multiple-story buildings. For instance, a Soviet chemical industry one-story plant building (span 18 meters, height 5-6 meters) has a construction cost of 400 rubles per square meter, while the cost for multiple-story plant building is at 500 rubles per square meter. Consequently, if the construction project is not limited by ground space, it is not advisable to use the narrow (less than 24-30 meters) multiple-story plant building design.

In many cases where the production process consists of a vertical production procedure, it is better to change the process into a horizontal production procedure so that the plant building can be changed into a one-story building. At the same time, whenever the load is greater than 1-1.5 tons per square meter, a one-story plant building should be adopted.

(d) In designing industrial plant buildings, there is another effective method to reduce the dead weight of the structure. This method stresses the importance of separating the beam structural members of the bridge-type cranes from the load supporting structural members of the plant building in the design. According to Soviet statistics, the four-span one-story plant building (the network of columns 18x6 meters, length 150 meters, height 8 meters) without bridge-type cranes has a structural dead weight of 100%, while a similar plant building that has a 5-10 ton crane has a structural dead weight of 116%, another similar plant building that has a 15-20 ton crane has a structural dead weight of 122%, still another similar plant building that has a 30 ton crane has a structural dead weight of 126%. The reason that the dead weight of structure continues to increase lies in the fact that there is the load of the crane equipment erected on the plant building structure, increasing the internal supporting strength of the columns and enalrging the cross-section of the columns. At the same time, with the crane beams, crane rails and the repair platform and other such structural members, the height of the plant building must be correspondingly realsed and haunched construction must be added to the columns. Of course, at present, the design for those plant buildings that have bridge-type cranes not only has the weakness of having an increased dead weight of structure but also has the limitation of beam span for the crane. As such, the distance between the columns cannot be

extended, restricting these plant buildings from many uses. Now, because of this fact, the trend in the Soviet Union is not to use the bridge-type cranes inside plant buildings for internal transportation but to use small vehicles, or continuous transportation equipment, or the new electrically operated tackle blocks, or door-type cranes, or air-compressed transportation lines and hanging cranes to substitute for the bridge-type cranes. Special attention must be given to this fact.

(e) In one-story plant buildings, the ⋀ shape or A shape sky-light structure should not be adopted because these types of structures have many weaknesses. First of all, they have sky-light frames, sky-light side walls and the structural members of the end partitions, which increase the load of the roof and at the same time, these structures aggravate the serious load distribution on the building frame works, changing them from receiving an even load to supporting a concentrated load. As a result, the materials for building frame must be increased and the structural dead weight is correspondingly increased.

Not only this, but after ⋀ shape or A shape sky-lights are erected, there will be an additional load from the wind and snow; the former is brought about by the increased building area while the latter is caused by the snow piled on the side of the sky-lights. This is quite a serious problem in places where the climate is very cold. If flat top sky-lights or roofs, no sky-lights are used, the above-mentioned weaknesses will be eliminated and furthermore, the construction cost for the roof will be lowered by 15-20%. In cold climate areas, such roof structures will reduce the possibility of losing heat through the glass structure of the sky-lights and the cracks in the sky-light panels. Loss through such means is generally more than 50% of the total heat lost through the entire supporting structure of the plant building.

(f) In certain industries, some enterprises are operated by equipment that are installed in open-air or partially open-air areas and do not require plant buildings to house or partially housing the technical equipment. Such enterprises naturally economize a great amount of construction materials. This method of not housing or partially housing the equipment in the plant buildings brings another convenience to production, because it enables the enterprise to transform its structure readily, and at the same time, the construction of such an enterprise can be done rapidly. Though this is the most thorough method to reduce the dead weight of structures, most enterprises now (much more so in

the future) cannot adopt this method because their equipment and products cannot be operated and manufactured in the open-air areas. According to present experiences, such enterprises as the cement factory, mining enterprise, heat-resistant materials plant, certain chemical industries and oil refinery can be operated in the open-air areas.

In civil construction, under certain conditions, the use of partition walls (internal walls) to support the load instead of relying wholly on the outside walls (external walls) is another method to reduce the dead weight of structures. In designing the external walls, it is often to make them very thick, not because they are required for their strength but because they are required to preserve heat, and as such, the materials so used are not employed to their fullest extent. If the internal walls are used to support the load and light materials are used for the construction of the external walls, the construction materials will be used to their fullest extent, and the dead weight of the walls will be reduced. Not only this, but to use the internal walls to support the load will reduce the span of the floor slabs (along the surface of the rooms but not along the depth of the building), and will form a continuous multiple-span series of slabs, whose thickness can be accordingly reduced.

Calculations have shown that internal walls load supporting, as compared to external walls load supporting, reduces the dead weight of structure by 160 kilograms per square meter. If there were 10,000,000 square meters of residential houses constructed each year throughout the country, there would be 1,600,000 tons of construction materials economized. Here attention must be called to the fact that internal walls load supporting does not under all conditions reduce the dead weight of structures as compared to the external walls load supporting, but in the over-all design, an economic comparison should decide the problem.

In addition, to reduce the height of stories in residential houses is another effective measure to reduce the dead weight of structures. For instance, the height of a story reduced from three meters to 2.7 meters will lessen the structural dead weight by 4-5%. In the Soviet Union, the height of a story has been reduced to 2.5 meters.

(B) Adopt high efficiency structural forms to reduce the dead weight of structure.

High efficiency structural forms can directly but not indirectly distribute the load on the supporting structure to foundations. The internal load of the structure is

an axial stress but not a bending stress. The high efficiency structural forms can fully utilize the load carrying capacity of the materials because the selection of the structural form is based on the materials. At the same time, the shape of their cross-section is generally composed of thin walls, hollowed center, and curved surface but not horizontal; accordingly, the structural dead weight is very small. At present, those principal high efficiency structural forms that should be mentioned here are:

In the field of steel reinforced concrete structural members:

(a) Fabricated pre-stressed steel reinforced concrete structural members: Owing to the utilization of high strength steel materials and reinforced concrete, these structural members not only enable the structure to become better (in respect to its ability to resist cracking, have better durability and to substitute for steel structural members in large spans), but also reduce the cross-section of the structural members, whereby the dead weight is also reduced. In an individual case where high strength steel materials and the No 1,000 reinforced concrete are used, it is possible to reduce the dead weight of the steel reinforced concrete structure down to close to that of a steel structure (if No 1,000 reinforced concrete is used to construct an 18-meter span of pre-stressed frame-work, the weight of each unit is 2.6 tons, which is equivalent to only 55% of the weight of a steel frame-work).

(b) Shell structure: Owing to its ability to distribute very rapidly the load of the roof to the external walls that support the structure, the internal load of the shell roof structure is principally an exial stress (most of which is pressure stress), so, the thin shell roof structure can fully utilize the merits of the load carrying capacity of reinforced concrete, uniting the roof structure load supporting ability and its protective function into one, so its thickness can be made very thin. At the same time, since the surface of the thin shell structure is a curve, its rigidity is very high. Owing to these advantages, to use a thin shell structure to cover a great span of a roof is an extremely favorable condition in reducing structural dead weight. This type of high efficiency structural forms has become more obviously acknowledged by the general public. The existing problem is to create more up-to-date thin shell forms, to develop fabricated thin shell structures and to further simplify their calculation methods so that this type of structures will serve the construction industry better.

(c) The structure of rolled plates: The structure

of rolled steel reinforced concrete plates is the most effective structure in construction. These plates can be used in internal and external walls, pre-stressed floor slabs and roofing plates. Their structure is formulated by steel reinforced concrete thin wall ribbed plates--shell plates. The external walls are erected by the joining of two shell plates, in between which a layer of asbestos for preserving heat is inserted. The internal walls may use one shell plate or may join two shell plates for their formation. Between the shell plates, dowels are inserted so that they can be easily welded together. These rolled plates give the finished products a very high strength and an accurate geometric measurement. They can make a thin wall as thin as one millimeter; thus they help to economize construction materials.

When the frame-work is welded together, for each square meter of living space, 0.334 cubic meter of concrete and 26 kilograms of steel are used. If mineral slag reinforced concrete plates are used for the construction of residential houses, the dead weight for each cubic meter is 470 kilograms, while pottery aggregate reinforced concrete wall plates are used, the dead weight will be 370 kilograms, and if rolled plates are used, the structural dead weight is only 226 kilograms. This is a reduction of about one-third to one-half.

The merit of a rolled plate structure not only lies in its ability to reduce the structural dead weight but also lies in the fact that the structural members can be produced on a factory basis, reducing the amount of labor required for its production and installation, extending the measurements for the plate structure, and reducing the necessity of re-processing, because the surface of the plates is very smooth.

All these facts help to hasten the speed of construction. At the same time, when these plates are rolled, heat is being generated so there is no necessity to apply a steam operation; therefore manufacturing time is shortened and plant production efficiency is also raised.

(d) The load carrying space structural unit: This type of structure is the most advanced type of fabricated structure for housing constructions. It is a single unit or a complete fabricated room as a unit, being a hexagon box-shaped structural member. The internal decorations or equipment of the room are completely finished at the factory and the completed room is then transported to the construction area where it is being erected. Such structural members can be used not only in residential homes but also in hotels,

public dormitories and hospitals. The space rigidity of these space structures has been greatly increased and the load on the cross-wise and length-wise internal walls is also reduced. The load supporting capacity of the construction materials is fully utilized. Accordingly, construction labor is greatly lowered and the plant building is completed within a shorter period of time.

According to Soviet statistics, residential houses that are constructed with these structural members have shown excellent technical and economic values: compared with large-size wooden structures and large-size fabricated structures, these fabricated room units have reduced the dead weight by 140-180 kilograms per cubic meter; the amount of steel used for the construction of houses per cubic meter is 4.5 kilograms; the amount of labor used at the construction area is 0.4 labor day; and the amount of reinforced concrete used is 0.08 cubic meter. Not only this, the adoption of these completed room units also reduces the quantity of installed structural members and a smaller variety of varying sizes of structural members.

For instance, to construct a pre-fabricated large wooden house, it needs more than 30 varieties of structural members of varying measurements, whereas the construction of a load carrying space structural unit needs only five varieties of structural members of varying measurements. This is advantageous to production based on a factory basis. Owing to the nature of these completed room units, the complicated installation of decorations, sanitary equipments all are done in the factory where quality and the high degree of industrialization can be guaranteed. Consequently, these structures have a very promising future in their development.

(e) Folded plate structure: The surface of this structure is formed by many horizontal broken-lines. Basically it is similar to the thin shell structure and has many similar merits, but its load carrying capacity is inferior to that of the thin shell structure. However, it has certain advantages that cannot be paralleled by the thin shell structure; that is, because it is formed by horizontal plates, its mould plates can be constructed more easily. At present, folded plate structure is not very widely used.

In steel reinforced concrete structures, besides the above several high efficiency structural forms, there are other forms for the cross-section of the structural members, such as hollowed center and thin wall structures, with which the goal of reducing the structural dead weight may be fulfilled. The most commonly seen are the hollowed

floor slabs and the hollowed fabricated foundation blocks. According to Soviet experiences, to use hollowed blocks to construct a foundation can reduce the dead weight of a strip-shaped foundation by more than 40% and the construction cost by 30-40%. It can be safely predicted that the employment of hollowed thin-wall cross-section structure will be widely applied in the future.

In the field of steel structure:

(a) Suspended structure: Suspended structures are mostly used in large-span roofing structures. In this type of structures, the principal load carrying structural members are the steel cables which support the stress; therefore high strength steel cables are used as load carrying structural members, as such, the materials are used to their fullest extent and the amount of materials used is greatly reduced. In addition, the materials used for the construction of these suspended roofing structures are generally of light-weight nature, such as wooden boards, water-proof painted corrugated iron plates, plastics, light-weight reinforced concrete plates and silicated plates; as the result, the whole roof structure is very light. Genrally, the weight of such roofing structure is about 100 kilograms per square meter, and compared with ordinary roofing structure, it is considerably lighter. At the same time, this type of structure can cover a great span, be formed easily, constructed conveniently, and can be made in various beautiful shapes. With these merits, suspended structures have been widely used in China within the recent years.

(b) Pre-stressed steel structure: Because of its merits, such as high strength, light structure, and manufacture on a factory basis, steel structures are very good construction materials. However, at present, China's steel production is not very great, so steel is reserved for use in those places where the need for steel is the greatest. Consequently, in the construction industry, steel reinforced concrete should substitute for steel structures. Though the general trend may be so, certain economic departments (such as the metallurgical, chemical and heavy machinery manufacturing industrial departments) still must use the steel structures because of the needs arising from the nature of production and the limitations arising from construction techniques.

In steel structures, one of the important measures to reduce structural dead weight is the adoption of pre-stressed steel structures. The principle for the construction of this type of structures is somewhat similar to that for the construction of pre-stressed steel reinforced concrete

structures. Generally there are two types of conditions: in one, the material strength in the structure has not been fully utilized (such as beams), then, pre-stressed should be employed to adjust the internal load distribution in the structure so that the material can be fully utilized. In another, the material strength in the structure has been fully utilized (such as trusses), then, add a high strength steel material to the structure to form a pulling lever so as to counteract a part or the entire internal load in the original structure, thereby, the load carrying capacity of the structure can be increased. According to past experiences, pre-stressed steel structures can economize 30-40% in steel materials and structural dead weight is also reduced.

(c) Light-weight lever steel structure: Among these structures, there are the thin-wall structures, the thin-plate box-shape structures, the cold-bent steel structures and the steel pipe structures. The light-weight steel structures have light dead weight, can be joined together by simple welding and can be constructed easily. These structures have a promising future for development.

According to experiences gained by the German Democratic Republic, a truss made by a light-weight steel structure can be designed to use a similar amount of steel as that used in a steel re-inforced concrete structure.

In the field of brick and stone structure:

(a) Vibrated brick wall plate structure: Under present conditions in China, bricks are still the principal materials used for load supporting and for the structure of protective walls. Indeed, they will be superseded by large-size wooden boards and large-size light-weight fabricated plates. However, at present, when considerations are given to how to reduce the dead weight of structures, the brick structure problem cannot be neglected. According to Soviet experiences, the present proportional weight of brick walls is still very great. Up till 1955, the production of a common brick wall in the Soviet Union still required about 50% of the total amount of construction materials for an entire wall. When in the Soviet Union the amount of materials is so great, in China the amount would be even greater. Thus, attempts must be made to reduce the dead weight of the brick walls.

Vibrated brick wall plates are the new structures that will fulfill this goal. They are formed by laying bricks in between mould boards, filled solid with mortar by vibration and pressing. A heat preserving layer may be added to the large-size brick wall plates, so that they can be used for the construction of external walls. These brick

walls plates have many merits; one of its principal merits is the reduction of structural dead weight of houses. The dead weight of one cubic meter of ordinary brick house is 540 kilograms, while that of one cubic meter of vibrated brick wall plate house is only 300 kilograms. The dead weight is reduced by more than one-third and the amount of bricks used is reduced by nearly two-thirds. Construction labor is also reduced by nearly one-half. The reason for these reductions lies in the fact that at present, in erecting a brick building of less than five stories, the thickness of the external walls is designed to meet the needs of heat preservation, so they are far thicker than the actual need for load carrying. In general, about 75% of the materials in the external brick walls are not fully utilized. Therefore, light-weight low heat-conduction materials should be used to make a layer of heat preserving structure to substitute for ordinary bricks.

In the erecting of load carrying internal walls, the work is generally not done properly, because the mortar placed in between the bricks is not solidly pressed. As a result, the strength of the brick wall is weaker than the bricks and mortar by about two-thids. In adopting the vibrated brick wall plates, the solidity of the mortar increases the strength of the finished wall. This is the fullest utilization of the mechanical properties of the bricks so used. Consequently, it is possible to erect walls of half-a-brick thickness to support the load of a building as high as five stories. In addition, in adopting the vibrated brick wall plates, it raises the degree of fabrication of wall structures. In the manufacturing process, there is no special equipment needed. Furthermore, wall decorations and painting can be done before the plates are constructed into walls, so this is another advantage by which construction can be hastened.

(b) Non-reinforced brick thin shell: In using a suitable curve-shape structure, it is possible to turn the internal stress of the entire thin shell into a compressive stress rather than a tensile stress. This type of non-tensile stress thin shells can be wholly made of bricks and can be made in a thickness one quarter that of a brick. This type of structure has the merits of the thin shell structures as mentioned in the above discussion. It is worthwhile to spread this information. At present, this type of structure is quite widely used in Kwangtung Province, but the measurements for the non-reinforced brick thin shell that has been adopted in construction are not very large.

(c) Make use of advanced theories for structural

calculations: Advanced structural calculation theories also can reduce the dead weight of structures. At present, structural theories based on the ultimate design calculations are very advanced theories. They are far superior to those that are based on allowable stress and failure condition calculations. They are more suited to actual structural conditions and can fulfill more economical structural planning. According to statistics, a roofing plate whose measurements are 1.5x6 meter, when it supports a load of 650 kilograms per square meter, the dead weight of the roofing plate, in accordance with the ultimate design calculation, is 100%, but if it were based on the former method of calculation, the dead weight of the roofing plate would be 119-125%.

When columns are supporting various types of loads, the dead weight, based on the ultimate design calculation, is 100%, but if it were based on the former method of calculation, the dead weight would be 121-180% (eccentric load, without longitudinal bending), or 139-240% (axial load, without longitudinal bending). It is obvious that by applying advanced structural calculation theories, the reduction of structural dead weight can also be attained.

(2) Adopt light-weight high-strength construction materials for load supporting and protecting structures in buildings so as to reduce the dead weight of structures.

Another important way to reduce the dead weight of structures is the adoption of light-weight high-strength construction materials for load supporting and protecting structures in buildings. Several principal light-weight high strength materials are discussed in the following:

(A) High strength steel materials: Principally they consist of: (a) high strength steel wires; their maximum strength generally is 15,000-20,000 kilograms per square millimeter; (b) high strength steel rods; their maximum strength is 9,000-15,000 kilograms per square millimeter; (c) steel cables; this steel material has the merits possessed by the above two types of steel materials. Steel cables are formed by binding a number of high strength steel wires together. They have a high stress and a large cross-section, so they not only economize on the amount of materials but are also convenient for construction, and at the same time they are easily bonded together with reinforced concrete. Furthermore, cables have a very good elasticity, which is suitable for the pre-stressed fabrication of a curved formation.

(B) High grade reinforced concrete: The application of high grade reinforced concrete can lessen the cross

section of the structural members and reduce the dead weight of the structures. The manufacturing of No. 1,000 reinforced concrete house framing has been successful. If the strength of reinforced conctete can be further raised, the dead weight of reinforced concrete structures will be able to match that of a steel structure.

(C) Steel mesh cement: Steel mesh cement is a new form of material, formed by laying several layers of steel mesh into a cement mortar. As compared to ordinary steel reinforced concrete, it has better isotropic, anti-creeping, elastic and tensile strengths. At the same time, the several layers of steel mesh inside the cement will increase its internal adhesion and bond strength. The steel mesh also distributes the shrinkage of the cement mortar, rendering the mortar more solid, which has a better reaction to penetration. With the several layers of steel mesh, the elasticity of the cement mortar is raised so much so that it can stand a certain degree of shock.

The steel mesh is generally made of 0.5-1.5 decimillimeter steel wires, with the mesh holes of 10-15 decimillimeters. Generally, the thickness of steel-wire mesh cement structure is 12-25 decimillimeters. If additional steel rods are inserted in the middle of the structure, the thickness can be increased to 60-100 decimillimeters. If steel wire mesh cement were adopted to make curved shape arch-type thin shell structures, the dead weight would be only 40-50% of that of the common reinforced concrete.

(D) Pottery aggregate reinforced concrete: Pottery aggregate is an artificially manufactured porour light-weight aggregate material. Its quality is light and hard. Its surface is comparatively small. It has a low water absorbing rate and does not contain any unfavorable elements. It can be mixed with any type of light-weight reinforced concrete. It can be used as wall plate or floor slab structures. Take external walls as an example, if No. 50 pottery aggregate reinforced concrete were used to make a 20-millimeter thick wall, the dead weight per square meter would be 133 kilograms, but under heat preservation requirements, an ordinary brick wall that has a two-and-a-half brick thickness of similar size would have a dead weight of 943 kilograms.

In the case of an 80-decimillimeter thick floor slab structure, if pottery aggregate reinforced concrete were used, the dead weight per square meter would be 120 kilograms, whereas, if multiple-ribbed steel reinforced concrete slabs were adopted, the dead weight per square meter would be 165 kilograms. Pottery aggregate reinforced

concrete is a high efficiency construction material. It can reduce dead weight and the construction cost.

(E) Pumice stone reinforced concrete: Pumice stones are sponge-like porous structures which also are natural light-weight aggregate materials. They are found in many parts of China and their deposits are very rich. If pumice stones were used to make reinforced concrete, it would have a pressure-resisting strength of 50-300 kilograms per square millimeter. It can be used to make load supporting structures in houses. At the same time, it has excellent sound-proof and heat-proof properties. It has a high heat resistence (700°C) and also is acid-proof. It can be sawed off into any thickness to be used as heat preserving materials.

(F) Asbestos cement products: The merits of asbestos cement are: light-weight, high strength, water-proof, incombustible, weather-proof and durable. At the same time, it can be made into any shape and takes paint readily. Therefore, it has a very promising future as a construction material. It can be used in industrial or residential buildings as roof, floor slabs and sanitary structural members. In using several layers of asbestos cement to form roof or floor slabs, the dead weight of structure can be reduced by 50-60% and the construction cost per square meter structure can be reduced by 20-25%.

In using a room-size asbestos cement wall plate, the dead weight per square meter can be reduced to 1/15 of the dead weight of a brick wall and the construction cost reduced by 30%. For instance, in a 64-millimeter thick solid load supporting brick wall, the dead weight per square meter is 1,250 kilograms, while a hanging wall made of a large-size asbestos cement plate (two pieces of thin asbestos cement plates, erected on an asbestos cement framework) and insert asbestos fibers as a heat-preserving layer, the dead weight per square meter is only 76 kilograms.

A two-story four apartment building, constructed with asbestos cement fabricated parts, has a total dead weight of 112 tons; that is, each cubic meter of building has a dead weight of 156 kilograms, while the dead weight per square meter is 740 kilograms, and compared to the dead weight of a brick building, the weight is reduced by more than two-thirds. Not only this, the asbestos cement products need very small amounts of cement. For example, a square meter of steel reinforced concrete needs 60-80 kilograms (even up to 100 kilograms) of cement, but a similar size asbestos cement product needs only 40-50 kilograms of cement. At the same time, owing to the high strength of asbestos

cement and its excellent ability to resist tensile stress, its products need almost no metal at all. The amount of metal needed for the manufacture of one square meter of asbestos cement wall plate is not more than one kilogram.

(G) Light-weight inflated large bricks: These bricks are made of rubberized clay, which becomes inflated after it is baked under a high temperature. The bricks' me-its are: light dead weight (each cubic meter has a dead weight of 462 kilograms), relatively high strength (the pressure-resisting strength of each square millimeter is 37.58 kilograms and the breakage-resisting strength of each square millimeter is 7.85 kilograms) and excellent sound-proof and heat-proof properties. The bricks are good heat preserving materials within 1,000°C temperature. They also can be used to make load supporting structures in low level buildings.

(H) Porous silicated pieces: These are different from the ordinary heavy reinforced concrete pieces. Their raw materials are very cheap (ordinary sand and coal slag), which, together with local adhesive materials (lime), form into silicated structures. Their characteristics are: (a) there are no rough aggregate materials in their compounds (broken stones and pebbles) but they are of granular structure; (b) their adhesive materials have a special property which is formed during the steaming and compressing treatment by the mutual reaction of calcium hydroxide and the silicon dioxide on the surface of the quartz sand.

Porous silicated pieces have a light weight (each cubic meter is within 700 kilograms) and can support quite a heavy load (their strength reaches 50-100 kilograms per square millimeter) and they also have a heat-proof property. Therefore, they can be used to make into large-size prefabricated pieces, wall plates and floor slabs, which greatly reduce the dead weight of structure, raise heat-proof property, economize cement and lower construction cost.

(I) Perlite and perlite powder: Perlite is the best light-weight construction material and sound-proof and heat-proof materials. It can be made into fine construction material that has a volume weight of 50-300 kilograms per cubic meter (the granule diameter ranges from 0.15-5 millimeters). Generally, in a rotating kiln, it is possible to produce the volume weight of 300-500 kilograms per cubic meter and the granule diameter 3-20 millimeters. Using it together with cement adhesive materials, light-weight reinforced concrete with the grade number ranging from 25-100 can be produced and its volume weight is 600-900 kilograms per cubic meter. This type of reinforced concrete is

suitable for load supporting in 4-5 story buildings and also for non-load supporting walls.

Perlite powder refers to the broken perlite stones whose diameter is under several decimillimeters. They are given a sudden heat treatment under a 1,000°C temperature. Through the expansion of the air bubbles, these broken stones become inflated and hollowed in the center, as natural glass semi-transparent and semi-grey granular materials. They are very light and their volume proportional weight is 0.04-0.2. They are fire-proof, water-proof, sound-proof and heat-proof. Besides being used as aggregate materials for reinforced concrete and mortar, they are good sound-proof and heat-proof materials.

(J) Mineral slag fibers and asbestos fibers: Mineral slag fibers are new heat preserving and sound absorbing materials. These are made by applying the steam or air blowing from 4-8 large air compressors to the hot smelt mineral slags. These fibers have many merits: small volume weight (150-250 kilograms per cubic meter), low heat conduction (0.04-0.06 kilo-calorie per meter. hour. degree), excellent sound-proof property, non-combustible, cannot be easily shaken, and are not affected by weather.

The more important fact is that they have a plentiful supply of raw materials. If a workshop is established near a blast furnace, these fibers can be made without fuels. Mineral slag fibers need very low production cost and can economize a great amount of fuels. In construction, a layer of mineral slag fibers with a thickness of 2.5-3 millimeters has a heat-preserving property which is equivalent to that of a brick wall that has a thickness of more than 50 millimeters.

Asbestos fibers, as mineral slag fibers, are new insulating, heat-preserving and sound-proof materials. Asbestos stones are melted by a high temperature into a liquid, which is diffused by hot steam and blown into a mist, which in turn is drawn into long fine fibers. Asbestos fibers have the same properties as those of the mineral slag fibers. In those areas where there is no mineral slag, asbestos fibers should be adopted.

(K) Aluminum and aluminum alloy: In the present construction industry, aluminum and aluminum alloy are becoming more widely used. Their merits are: small volume weight (2.7-2.8 tons per cubic meter, about 1/3 of the weight of steel), but they have the strength of No. 3 steel and under certain conditions, their strength is greater than that of steel. They are more durable than steel under any weather conditions. In the open air, after oxidization takes

place on aluminum, a thin coat is formed and it protects the aluminum from being further eaten by weather.

Through heat treatment and pressing, aluminum can be rolled into various types and shapes of structures. If aluminum structure is used to substitute for steel structure, the dead weight is reduced by 2/3 or even more. The greatest aluminum structure in the world is the Hartfield airplane hanger (span 66 meters, length 100 meters, and height 14 meters), its structural dead weight is only one-seventh of that of steel structure. However, it has weaknesses too. For instance, its elastic mould weight is small, only 700,000-800,000 kilograms per square millimeter (steel is $2.1x10^6$ kilogram per square millimeter). Consequently, aluminum structure has a greater possibility to lose its shape than a steel structure (about three times greater). At the same time, the coefficient of expansion of its temperature is twice as great as that of steel. As a result, this type of structure has a more readily temperature change. But, the above weaknesses can be overcome, only if the ring-shape or box-shape cross-section is adopted so that the strength of the structure can be increased. Such a structure remains a very good structure.

Aluminum and aluminum alloy structures can be joined together by rivets (it must be done by cold rivets, because hot rivets may cause annealing of the structure and lower the mechanical property of the alloy), welding, and high strength bolts or they may be joined together by glue or glue with high strength bolts. The adoption of such structural materials will greatly reduce the dead weight of structures.

(L) Plastics: The term plastics is a general name, which includes many compound materials. These materials contain many different chemical elements and physical properties. They have relatively great mechanical strength (close to the strength of steel alloy) and elasticity and they have small heat and sound conduction and low specific gravity (as the volume weight for foam plastics and porous plastics is 30 kilograms per cubic meter). Plastics do not rust and they are not affected by weather, so, when plastics are used as structural ribs, their strength is twice as high as steel. On account of this, plastics can substitute for steel structures. Plastics can be used in industrial and civil construction as load supporting or non-load supporting structural members and parts. For example, if plastics are used for the construction of walls, they are more solid than brick walls and their dead weight is lighter than that of the latter by many times (a plastic wall made of two porous

or foam plastic plates is lighter than all other types of walls by two-thirds to three-fourths of their weight). They have very small heat conduction. They take paint readily. They can be made in any one color or the imitation of any natural material (such as granite).

Plastics can be used to make sanitary equipment, the entire structure, including the partition wall, floor tiles, ceiling, bath tub, basin, toilet bowl, pipings, ventilation equipment, and all the other accessories of sanitary equipment in the house, and has a total dead weight (including the complete equipment) that does not exceed 350 kilograms.

If "foam amino-plastics", nebular and porous plastics are used to serve as heat-proof materials, in the framework of a house the dead weight of the structure can be reduced to 100-150 kilograms per cubic meter. Rubber compounds together with glass fibers or glass cloth can be coordinated to form into good heat-proof and sound-proof materials or to be made into load carrying wave-like roof plates, pressure water pipes, telephone poles and other load supporting bending structural members. Each square meter of plastic roof plates has a dead weight of 2-2.5 kilograms, permits 85% of the sun rays and ultra violet rays to go through the plates and can supporting an effective load of 400 kilograms per square meter. The chemical properties of the plastics enable their products to become solid and durable and at the same time to have an insulating property. Plastics can be made into any shape through heat treatment and they can be easily joined together or glued together.

Glass fibers can be compressed into compound materials, which are called elastic plastics. They are not affected by steam crystallized products and have a strong fire-proof property. These plastic materials can be made into doors and windows. They are better than wood because they do not shrink, nor expand, nor warp. Use compounded ethyl ether and tree rubber into plastic glass to serve as transparent roof plates and sun-porch protecting structures. This glass has a high strength, is incombustible and is not affected by weather. Plastics have many merits. They will be widely employed in the construction industry and have a very broad development in the future.

3. Several Problems Concerning the Reduction of Dead Weight of Structure

(1) As said in the above, in construction designing, to put great efforts in the reduction of dead weight of

structure is a very important problem that is confronting us now and that we have to overcome. But in overall designing, attention must be given to the coordination of reducing the dead weight of structure and the economy of valuable construction materials, of reducing the dead weight of structure and the utilization of local construction materials, of reducing the dead weight of structure and the construction technical level at the time and at the place, or perhaps, it may be said, attention must be given to the coordination of future outlook and the present outlook.

If looking only from the view point of reducing the dead weight of the structure, it is better to use steel structure than to use steel reinforced concrete structure because the strength of material of the former is greater than that of the latter. However, at present, China must use steel reinforced concrete structures to substitute for steel structure in order to economize valuable steel materials.

Again, looking from the view point of reducing the dead weight of structures, bricks and stones are not very ideal construction materials. However, in many areas, now there is still a lack of a better construction material, while bricks and stones can be obtained from the local areas and their supply is very immense. Under such circumstances, we must use bricks and stones to fulfill our construction task. Of course, we must give more consideration to the structural shape of the brick and stone structures so as to adopt the most reasonable new structural shapes for the reduction of the dead weight of structure. Looking from the view point of reducing the dead weight of structure, space structure is definitely lighter than horizontal structure. At the same time, we must also remember that the construction of space structure is more difficult than that of a horizontal structure. In using space structures, consideration must be given to the overall local conditions, construction factors and technical level.

In short, in all the ways that the reduction of the dead weight of structure may be accomplished as we have enumerated in the above discussion, some of them are nothing but distant pictures as far as some areas and units are concerned and they are not realities. For example, the application of aluminum alloy and plastics can definitely reduce the dead weight of structure, but at present, these materials are far from sufficient, so they cannot be universally employed in construction. Accordingly, while we are considering the reduction of the dead weight of structure, we must give attention to the other factors and to make an all-out consideration so that we may fulfill our goal in a

"more, faster, better and cheaper manner".

Here, we must especially point out that we too are opposing those who stress the importance of the factors of difficulties and material limitations and do not actively create conditions for the application of the many new structures and new materials to reduce the dead weight of structure.

(2) The reduction of the dead weight of structure must start with big factors. We must improve structure space and plain arrangement and adopt high efficiency structure and new materials. We must not rely on small factors which may affect the safety of the structure. Here is an example to illustrate the point: a certain designing institute adopted an un-prestressed polygon-shape house framing (18 and 24 meters). The framing dead weight was light and used a small amount of steel. Its construction cost was low. All prestressed house framings cannot compare with it. The designer had actually shown great talent in these respects. But, this framing has its own weaknesses, that is, it relied too much on certain factors. For instance, the cross-section of the framing members was too small, while the joint between the sky-light framing and the horizontal bracings with the house framing was too simple, rendering the rigidity of the joint between the structure itself and the structural members too weak. After construction began, the framing had to be strengthened. As a result, more steel materials were used. Therefore, in adopting such a method to reduce the dead weight of structure, it actually affected the safety of the structure. This method is not suitable.

(3) While we try to reduce the dead weight of structure, we must give attention to the entire and partial stability of the structure. Because we are employing more and more high strength materials, structural members become more and more delicate, thinner and thinner. From now on, the possibility of structures breaking down due to insufficient strength of the structural members, becomes relatively fewer, while the possibility of destroying the structure on account of the loss of the entire and partial stability of the structure, becomes greater. Consequently, the problem of structural stability will become an important item in the agenda for the conference. At present, our knowledge and experience in this field are far from sufficient and we must make plans far in advance.

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